

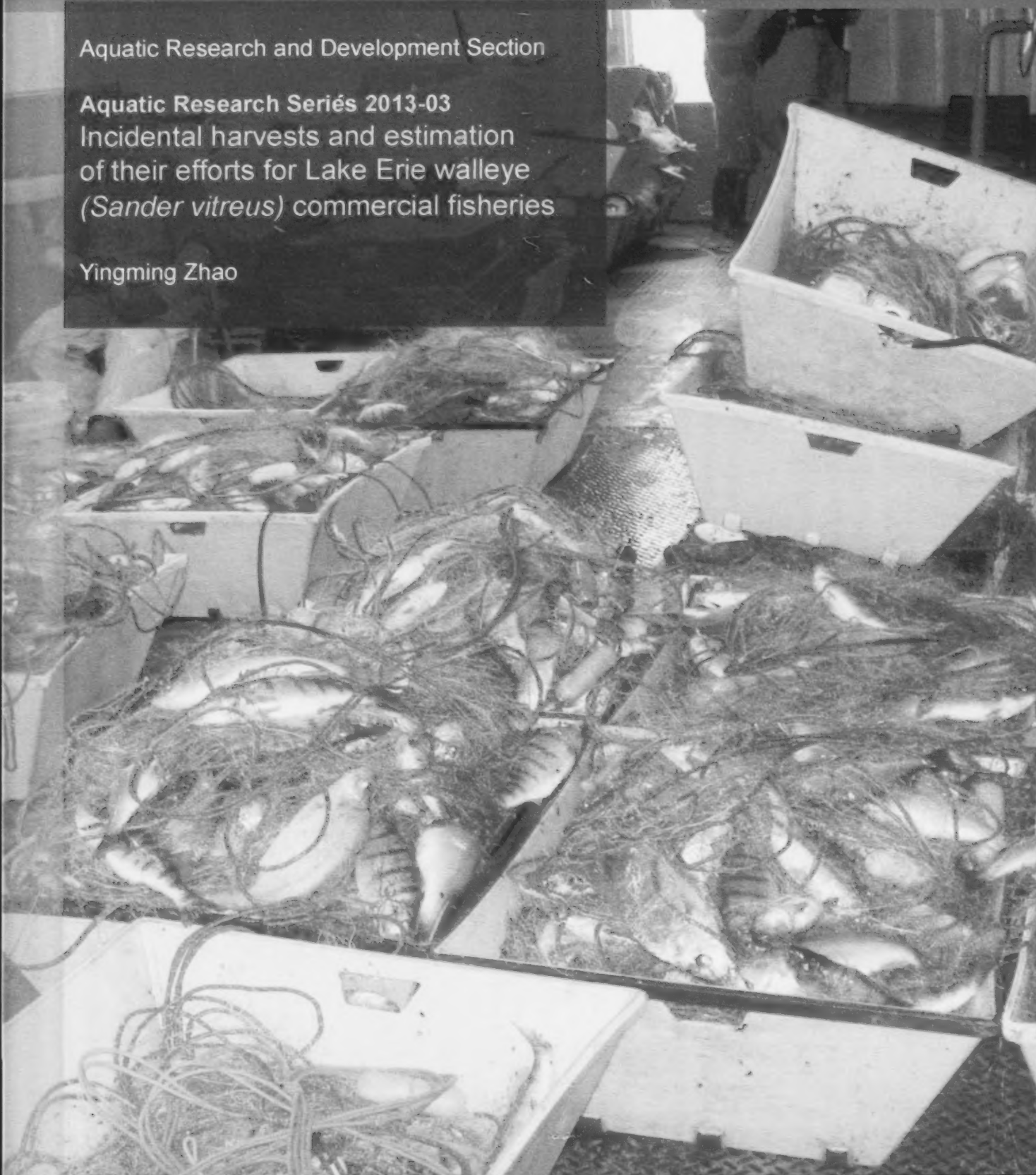
Natural. Valued. Protected.

Aquatic Research and Development Section

Aquatic Research Series 2013-03

Incidental harvests and estimation
of their efforts for Lake Erie walleye
(*Sander vitreus*) commercial fisheries

Yingming Zhao



April 2013

Incidental harvests and estimation of their efforts for Lake Erie walleye (*Sander vitreus*) commercial fisheries

© Queen's Printer for Ontario, 2013

Printed in Ontario, Canada

MNR 52722

ISBN 978-1-4606-1851-6 (Print)

ISBN 978-1-4606-1852-3 (PDF)

This publication was produced by:

Yingming Zhao
Aquatic Research and Development Section
Ontario Ministry of Natural Resources
Peterborough, Ontario
K9J 8M5

Please send comments to Yingming Zhao at yingming.zhao@ontario.ca.

This technical report should be cited as follows:

Zhao, Y. 2013. Incidental harvests and estimation of their efforts for Lake Erie walleye (*Sander vitreus*) commercial fisheries. Ontario Ministry of Natural Resources, Aquatic Research and Development Section, Aquatic Research Series 2013-03.

Cover photo: sorting commercial fish harvest

Photo credits: Yingming Zhao, MNR

Cette publication hautement spécialisée *Incidental harvests and estimation of their efforts for Lake Erie walleye (Sander vitreus) commercial fisheries* n'est disponible qu'en anglais en vertu du Règlement 411/97, qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec le ministère des Richesses naturelles au yingming.zhao@ontario.ca.

Abstract

Incidental catch and harvest of a fish species is the catch from the fisheries that are not targeting the species but retain the catch for fishers' harvest. Commercial harvest of walleye in Lake Erie consists of targeted and incidental harvest. From 1993 to 2009, Ontario's multiple species commercial fisheries produced an average of around 530 000 kg incidental harvest of walleye per year, and the number was translated to 0.020 exploitation rate or 0.024 fishing mortality rate for the period. The catch-per-unit-effort (CPUE) of walleye-targeted gillnets showed spatial and temporal patterns likely created by walleye migration and schooling behaviours. Accounting for such spatial and temporal heterogeneity, a geo-statistical approach was developed to estimate incidental catch effort for 2004 and 2005 and compared to the current assessment protocol. The current assessment protocol using a coarse spatial resolution and ignoring temporal patterns underestimated annual incidental catch effort by 52.5% and 158.7% or total effort by 28.0% and 28.3% for 2004 and 2005, respectively, implying the CPUE calculated from targeted fisheries likely overestimate walleye abundance. The study suggests incorporating the spatial and temporal components to standardize fishing effort whenever and wherever possible.

Keywords: Walleye, the CPUE, Incidental catches, Standardized Fishing Effort, Ordinary Kriging, Mixed Commercial Fisheries, Lake Erie

Résumé

La prise et la récolte par mégarde d'une espèce de poisson sont les prises obtenues lors de pêches qui ne ciblent pas cette espèce, mais dont la prise est retenue et récoltée par les pêcheurs. La pêche commerciale au doré jaune dans le lac Érié prend la forme de récolte ciblée et de récolte par mégarde. De 1993 à 2009, la pêche commerciale d'espèces multiples a produit une moyenne de 530 000 kg de doré jaune récolté par mégarde par année, ce chiffre se traduit par un taux d'exploitation de 0,020 ou par un taux de mortalité de 0,024 pour cette période. Les captures par unité d'effort (CPUE) de doré jaune ciblé effectuées à l'aide d'un filet maillant ont dégagé des régimes spatiaux et temporels probablement créés par les comportements migratoires et de rassemblement en banc du doré jaune. Étant donné cette hétérogénéité spatiale et temporelle, une approche géostatistique a été élaborée afin d'estimer les efforts de prise par mégarde en 2004 et en 2005 et de les comparer au protocole d'évaluation actuel. Le protocole d'évaluation actuel qui utilise une résolution spatiale grossière et qui ignore les régimes temporels a sous-estimé les efforts annuels de prise par mégarde de 52,5 % et de 158,7 % ou l'effort total de 28,0 % et de 28,3 % pour 2004 et 2005 respectivement, ce qui implique que les CPUE calculées à partir des pêches ciblées ont probablement surestimé l'abondance en doré jaune. Cette étude suggère d'intégrer les composantes spatiales et temporelles afin de normaliser les efforts de pêche à l'endroit et au moment opportun.

Mots clés : doré jaune, CPUE, prises par mégarde, efforts de pêche normalisés, krigeage ordinaire, pêche commerciale mixte, Lac Érié



Introduction

Walleye (*Sander vitreus*), a cool-water fish species, can only be found in North America's freshwater ecosystems and is well-adapted to local climatic conditions (Zhao et al 2008, Scott and Crossman 1998, Colby et al 1979). As a top predator, walleye plays an important role in shaping fish communities. The species is also one of the most valuable species for freshwater fisheries and sought by both commercial and recreational fishers (Scott and Crossman 1998). Lake Erie walleye fisheries have likely been maintaining the largest walleye fisheries in the continent (Regier et al 1969). From 1993 to 2009, the Ontario Lake Erie commercial fishery, primarily a gillnet fishery, annually harvested an average of 3,200 metric tons (2.72 millions walleye), approximately 60% of the total lakewide harvest. The recreational fishery claimed the rest of the harvest (WTG 2009).

In Lake Erie, walleye resources are shared among the U.S. states of Michigan, Ohio, Pennsylvania, New York and the Canadian province of Ontario (WTG 2009). The commercial fishery for walleye is only permitted in Ontario, and the main fishing gear is monofilament gillnets. Harvest of walleye is only by the recreational fisheries in the U.S. portion of the lake. Annual assessment of walleye resources is conducted by the Walleye Task Group (WTG), a bi-national organization, under the auspices of the Lake Erie Committee (LEC) of the Great Lakes Fishery Commission (GLFC). A statistical catch-at-age (SCAA) model is used to estimate walleye abundance, survival rate, fishing mortality (exploitation rate) and other management parameters. Annual harvest quota is determined based on the estimated abundance at the beginning of the current year and is allocated among the shared jurisdictions (Locke et al 2005). The international quota zone spans the western two-thirds of the lake (i.e., management units 1 to 3 in Figure 1).

Historically, the assessment and quota management of walleye resources in Lake Erie experienced three main periods. From the late 1970s to the late 1980s, fishable stock sizes and age structures were firstly established for the period of 1963-69 and a sequential projection approach was used to derive the standing stock size for the current year. Annual recruitment was predicted by a relationship between a young of year (YOY) survey index and estimated number of the fish recruited to the fisheries for the reference period (Hatch et al 1987). Gulland (1970)'s formula, constant harvest rate and abundance-dependent harvest rate were progressively used to calculate annual total allowable catch (TAC) (Hatch et al 1987).

In the early 1990s, a large discrepancy between the sequential projection of age structure and field survey estimates led to a new approach, based on a then newly-developed catch-at-age analysis using the CAGEAN code (Deriso et al 1986). The current fishable stock was estimated through CAGEAN and a yield-per-recruit analysis (Beverton and Holt 1957) was conducted to derive the optimal fishing rate (Henderson et al 1990, Locke et al 2005).

An almost consistent 15-year decline in walleye abundance, observed in 2000, created a concern about the collapse of the population. In order to reverse the decline and rebuild the population, the LEC implemented the Coordinated Percid Management Strategy (CPMS) from 2001 to 2003 and set a maximum level of walleye harvest as 3.4-million fish, less than 40% of the average TAC for the past ten years (1991-2000). The current stock assessment model, i.e. the SCAA implemented by the AD Model Builder (ADMB), was adopted in 2004 and an abundance-dependent harvest rate has been used to calculate the TAC since 2005 (Locke et al 2005). Zhao et al (2011) provided a detailed description on current walleye resource status and the quota allocation in Lake Erie. The WTG (2009) has reported annual abundance estimates, quota allocation and realized harvests by each jurisdiction from 1978 to 2009.

A total of 188 commercial fishing licenses share the Ontario walleye quota and each license is constrained to a specific harvest zone (management units, Figure 1). More than 99% of the licenses are for gillnets that mainly target walleye, yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), white bass (*Morone chrysops*), white perch (*Morone americana*), etc., or for trawl nets that mainly target rainbow smelt (*Osmerus mordax*). The remaining licenses are for trap or hoop nets, hook lines and seines (unpublished information from the Ontario Ministry of Natural Resources). Ontario commercial fisheries can be considered as mixed fisheries because each commercial gear targeting one or two specific species also catches and harvests other species. Ontario commercial fishing regulation requests that all commercial gillnets must have a minimum stretched

mesh size of 57 mm (2.25") and the gillnets targeting walleye must have a minimum stretched mesh size of 89 mm (3.5"). Therefore, measurement of the commercial fishing effort targeted on walleye has been based on the amount of large mesh gear (i.e. mesh $\geq$ 89 mm). Walleye catches from other gillnets (i.e. mesh sizes $<$ 89 mm) and other gear types (e.g. trap/hoop nets, trawl nets) may also be retained to fulfill annual quotas. This harvesting of walleye is referred to as incidental harvest, following the FAO (1996)'s definition of this term.

The commercial fishing effort related to walleye is an important input variable in the annual assessment of walleye abundance. The effort for the walleye-targeted gillnets is directly available from the Daily Catch Report (DCR) completed by each commercial fishery licence holder or designate for each fishing trip. The effort from other gear (i.e., resulting in incidental harvest of walleye) is also included in the stock assessment exercise, but requires some adjustment when estimating total walleye effort. The current method of standardizing walleye incidental catch effort is: (1) calculate the annual mean of the catch-per-unit-effort (CPUE) of the walleye-targeted gillnets, (2) aggregate all incidental catch harvest for each year, (3) standardize the incidental catch effort by dividing total incidental catch harvest by the CPUE derived from step (1), (4) repeat the steps (1) to (3) for each management unit (a coarse spatial resolution) in Figure 1, (5) calculate annual lakewide commercial fishing effort by summing over all management units the walleye-targeted effort and incidental catch effort derived in (4). This approach uses coarse spatial observations (i.e. the management unit) and ignores temporal (monthly) variations of the CPUE. Consequently, it potentially produces biased estimates of the incidental catch effort. In addition, stock assessment using the effort derived from this approach essentially assumes that the CPUE of walleye targeted gillnets represents lake-wide walleye abundance. Many studies showed that the CPUE from targeted fisheries tended to overestimate fish stock size, especially for a overexploited population due to hypo-aggregation. Targeted fisheries most likely concentrate on the areas where the targeted fish species form schools resulting in hypo-aggregation. It should be possible to use the catch from non-target fisheries from the areas other than those with high concentrations of targeted fish species to reduce the hypo-aggregation effect.

In this study, I used information collected from Ontario's commercial fisheries to (1) identify walleye incidental catch patterns; (2) estimate the incidental exploitation rate and fishing mortality rate for walleye from Ontario mixed commercial fisheries; (3) present a geo-statistical approach to estimate walleye incidental catch effort by incorporating the spatial and temporal variations of the walleye-targeted CPUE; (4) compare the effort estimates between the current assessment protocol and the spatially-temporally explicit approach presented in this study; (5) make management suggestions for walleye commercial fishery in Lake Erie.

Methods

Ontario Commercial Fishery Daily Catch Report (DCR)

Commercial fishery licence holders in Lake Erie are required to complete the daily catch report (DCR) for all fishing activity. They record landed species names and weights, gear types and efforts, targeted species, fishing time and locations, landing time and port names, and other fishing status. The DCR for each fishing trip has to be submitted to the Ontario Ministry of Natural Resources (OMNR) on completion of the trip. Lake Erie Management Unit (LEMU) of the OMNR process information from the DCRs and produce a summarized commercial fishery database for each fishing activity, including realized harvests and efforts. For this study, I extracted walleye incidental catch information from the database, including landed weights, gear types, and targeted species for the period from 1993 to 2009 to identify incidental catch patterns. However, the information about detailed catches for other species in addition to walleye and the targeted species is only available after 1998. For each year, the

incidental harvest was converted to incidental exploitation rate (u) by the equation: $u = \frac{\text{incidental catch}}{\text{lakewide abundance}}$, where the lakewide walleye abundance was reported in WTG (2009). The instantaneous incidental fishing mortality rate (F) was calculated through solving the following non-linear equation using the Newton-Raphson method: $u = F / (F + M) * (1 - \exp(-(F + M)))$, where u is the exploitation rate derived above and M is natural mortality rate assumed to be 0.32 (WTG 2009)

I applied two sample t-test to investigate the effects of implementation of the Coordinated Percid Management

Strategy (CPMS) on observed walleye incidental catch before and after the CPMS and also examined the relationship between walleye incidental harvest from Ontario mixed commercial fisheries and total lakewide walleye abundance reported in WTG (2009).

Estimation of incidental catch effort

Walleye harvests are reported by 5-minute grids and management units (Figure 1). A monthly mean for the walleye-targeted CPUEs and a monthly total of the incidental catches were calculated and mapped for each grid. For those incidental catches that occurred in the grids where the walleye-targeted CPUEs were available, incidental catch efforts for the grids were estimated by dividing the incidental catches by the CPUEs of the grids. However, many incidental catches occurred in grids where there was no targeted gillnet effort. Therefore, I adopted an ordinary kriging approach (see below for a definition) to interpolate the walleye-targeted CPUE values for the quota area covering walleye commercial harvest and matched the interpolated CPUE for each incidental catch. The matched pairs of the estimated CPUE and the incidental catch by grid were used to calculate the incidental catch effort. I summed effort over months and grids to derive total effort for each year. To demonstrate the impact of more detailed temporal and spatial information on estimation of incidental effort, I picked two years to represent low (2005) and high (2004) levels of incidental catches (proportion of total commercial harvest). The results were compared to the ones derived from the current assessment protocol described in the Introduction.

Ordinary kriging is a geo-statistical technique used to interpolate a stationary random variable at an unobserved location from the observed locations nearby. Among all spatial interpolation techniques, ordinary kriging is identified as a method providing a B.L.U.E. —best linear unbiased estimator (Isaaks and Srivastava 1989). Kriging assumes that the interpolated variable (i.e. walleye-targeted CPUE in this study) is a random variable following a spatially-stochastic process. The realisation of the process, i.e. observations of the CPUEs in different grids in this study, does not depend on their locations, but on their distances and directions. A same joint probability distribution is assumed for any pair of locations separated by a particular distance regardless of their locations: the assumption of stationarity (Isaaks and Srivastava 1989).

ESRI's ArcGIS v9.2 was used to carry out ordinary kriging analysis and the following steps were implemented:

Step 1: Examining the data distribution: A logarithm transformation was made for walleye-targeted CPUE to satisfy the requirement of normality by kriging if necessary.

Step 2: Identifying trends: In order to satisfy the assumption of stationarity, a trend analysis was completed and the trends (linear or quadratic) were removed if they were detected. However, the removed trend if any was involved in the final interpolation procedure.

Step 3: Fitting semi-variogram models: An empirical semi-variogram is a plot of semi-variances indicating spatial correlation of the CPUE at a distance versus distance classes, i.e. spatial lags. Two main purposes for analysing empirical semi-variogram were to (1) identify a spatial pattern (or spatial continuity) of the CPUE and (2) develop a mathematical model to describe such pattern. The model was thus used to set the weights of the neighbours of an interpolated location in the following steps. A commonly used spherical model was used to fit the empirical semi-variogram and the grid size was used to resolve spatial continuity in this study (Isaaks and Mohan Srivastava 1989).

Step 4: Incorporating anisotropy into the semi-variogram models: It is common that an empirical semi-variogram changes with the direction (Legendre and Legendre, 1998). For example, for a certain direction, the decline of spatial continuity is not the same as that in other directions. The directional influences are called anisotropy in contrast to isotropy and can be quantified as an ellipse shape with major axis indicating maximum continuity and minor axis minimum (Isaaks and Srivastava 1989). In this study, anisotropy of the CPUE was examined and accounted for during kriging interpolation whenever directional influences were detected.

Step 5: Interpolating the CPUE surface map: The semi-variogram models developed from above steps were used to interpolate walleye-targeted CPUE for each grid. During the interpolation, several sets of neighbour searching parameters (number of neighbours: 5 categories—5, 10, 15, 20, 30, and sector type: four types-1, 4 (two configurations), 8) were tested, and the model with the best combination of the parameters was selected according to the cross-validation analysis described in the next step

Step 6: Performing cross-validation analysis: A cross-validation analysis provides a quantitative measure on how well the model predicts unknown values. The analysis sequentially discards observed samples one at a time and

estimates its value using the remaining samples. The estimated value is then compared to the observed value (i.e. the discarded one). The procedure is repeated for each observed sample, from which a summary statistic, mean squared error (MSE), can be derived to indicate the predictability of the tested models, and the best model is the one with minimum MSE (Isaaks and Srivastava, 1989). In this study, cross-validation was used to select among neighbourhood searching parameters in step 5 (Päröma and Roa, 2003).

The above procedures were repeated for each month from April to December for the selected years. There is no sufficient data either for walleye-targeted CPUE or the incidental catches in the modelling area for January, February, and March.

Results

Annual commercial harvest of walleye in MU1 was the highest among all management units and slightly more than the sum of those from MU2 and MU3 (Figure 2a). The walleye-targeted CPUE was also highest for MU1 (Figure 2b). However, the percentage of incidental catches in the total harvest of walleye is highest for MU2. The highest proportion (54%) of lake-wide walleye incidental catches from 1993 to 2009 was observed in 2004 (Figure 2c). From 1993 to 2009, annual walleye incidental catch from Lake Erie mixed commercial fisheries was about $525,922 \pm 177,602$ kg ($\pm$ S.D.) or $21\% \pm 14\%$ ($\pm$ SD) of total walleye commercial harvest. The calculated incidental exploitation rate and fishing mortality rate both varied year to year with the means of 0.020 and 0.024, respectively (Figure 3a). In general, the proportion of incidental catches was higher for the post-CPMS than the prior-CPMS ($t_{15}=5.21$, $p<0.01$) (Figure 2c). However, no significant difference was observed on the incidental exploitation rate ($t_{15}=1.61$, $p=0.063$) or fishing mortality rate ($t_{15}=1.61$, $p=0.063$) between prior-CPMS and post-CPMS. Walleye incidental catch from 1993 to 2009 was not related to lake-wide abundance of walleye aged 2 and older ($F_{1,15}=1.51$, $p=0.238$) (Figure 3b), but the proportion of the incidental catch was negatively influenced by the lakewide TAC levels ($F_{1,15}=33.46$, $p<0.01$): the lower the TAC, the higher proportion of incidental harvest (Figure 3c).

From 1998 to 2009, on average, gillnets contributed $97\% \pm 1.1\%$ ($\pm$ S.D.) of total walleye incidental catches, and trawls about $2.6\% \pm 1.1\%$ ($\pm$ S.D.) (Figure 4a). The gillnet targeting white bass caught more than half ($64.2\% \pm 13\%$ ($\pm$ S.D.)) of incidental catches and much higher than other fisheries: $14.7\% \pm 17.2\%$ ($\pm$ S.D.) for yellow perch gillnets, $13.6\% \pm 8.2\%$ ($\pm$ S.D.) for lake whitefish gillnets, $5.0\% \pm 3.4\%$ ($\pm$ S.D.) for white perch gillnets and $2.4\% \pm 1.3\%$ ($\pm$ S.D.) for trawls (Figure 4b). The small-mesh gillnets for yellow perch and white perch and the trawls for rainbow smelt together contributed about $22.1\% \pm 15.8\%$ ($\pm$ S.D.) of the total walleye incidental catches.

The results of ordinary kriging were summarized in Table 1. Walleye-targeted CPUEs, for all selected months of the two years, showed strong skewness to the right (i.e. a few large values of the CPUE were present in each month) and a logarithm transformation was applied for the CPUEs to satisfy the normality assumption prior to a trend analysis and kriging estimation. A linear trend for both north-south and east-west was detected and removed for most months of the two years, while a quadratic trend for a few months in 2005. For most months, directional influences were identified for the walleye-targeted CPUEs and the maximum spatial continuity was oriented in the northeast-southwest or east-west direction. Isotropy of the CPUEs, i.e. non-directional influence, was observed only for two months, July of 2004 and November of 2005.

Interpolated maps for the walleye-targeted CPUE in 2004 and 2005 (Figures 5 and 6) reveal some common patterns of the spatial distribution of the CPUEs. An increase (a continuing pattern) in the CPUE from west to east was evident from April to June for both years. However, the trend seemed reversed for July, August and September. Multiple peaks (a discontinuing pattern) of the CPUEs were present in different regions of the lake for October, November and December of 2005, and for October and December of 2004. The estimated efforts using the geo-statistical approach (ordinary kriging) were higher than those using the current assessment protocol (i.e. arithmetic mean accounting for coarse levels of resolutions for spatial (management units) and temporal (year) structures of the CPUEs). From April to December, when compared to the geo-statistical approach, the current assessment protocol for the incidental catch effort estimation underestimated total incidental catch efforts by 52.5% and 158.7% or total effort (i.e. the sum of incidental effort and targeted effort) by 28.0% and 28.3% for 2004 and 2005, respectively (Figure 7a, b).

Discussion

The study reported that the west end of Lake Erie, MU1, supported almost half of Ontario's walleye commercial harvest. If a proportional relationship can be assumed between walleye-targeted CPUE and the abundance, then annual average walleye abundance in the west basin was the highest, at least, in the Ontario portion of Lake Erie. The result was consistent with the existing knowledge about Lake Erie walleye: walleye population in the west basin is the largest and supports the majority of the lakewide harvest, and the harvests in other regions of the lake are mainly composed of the west-basin walleye migrants (Zhao et al, 2011; WTG, 2009). The central basin, combining MU2 and MU3, produced the highest proportion of the walleye incidental catch harvest, which reflected the highest fishing activities for other species in the region, especially white bass, yellow perch and lake whitefish.

The walleye TAC experienced an average of 53% reduction after implementation of the CPMS in 2001 and remained in a low level for the following years except for 2006 when a historical record of walleye recruitment from the 2003 year-class fish was observed (WTG, 2009). Coping with the reduction, Ontario commercial fishermen reduced walleye-targeted fishing effort lakewide and allocated more gillnet effort for other species. Therefore, the proportion of the incidental harvest has increased with the decrease in the TAC since 2000. Negative association between the proportion of incidental harvest and TAC seems to be reasonably true and could be extended for all other mixed fisheries in other regions. When the TAC decreases, the targeted harvest decreases. However, incidental harvest may remain at the same level or increase due to increased fishing targeted on other species. The net effect is an increase in the proportion of incidental harvest, and therefore, it becomes increasingly important to accurately estimate incidental fishing efforts under such circumstances.

The lake-wide total abundance is not a factor determining the level of incidental harvest and the incidental harvest rate and fishing mortality remained relatively constant during the 18-year period for Lake Erie walleye. This may suggest that it is not an easy task to define the incidental harvest rate for fish species. Several factors including the abundance, TAC for both walleye and other quota species, and non-targeted fishing effort, fish behaviours (e.g. migrations) and other socio-economic factors may interactively influence fish incidental catches. Regulating incidental catches requires a comprehensive understanding of these factors.

Gillnets are still the most dominant fishing gear catching walleye in Lake Erie. A finding from this study is that a large proportion of walleye incidental catches were from large-mesh (>89mm) gillnet fisheries targeting white bass and lake whitefish. However, on average, more than 20% of the incidental catches were collected from the small-mesh gillnets targeting yellow perch, white perch and the trawls for rainbow smelt. During the late 1990s (1998 to 2000), the proportion was close to 45% on average. It is expected that the small-mesh gillnets and the trawls are able to catch small, unmarketable sizes of young walleye. Some yearling walleye were likely released or discarded with little expectation of surviving over the long-term gilling or tangling on the nets. Discarded walleye from incidental catches may or may not be recorded on the daily catch reports. Therefore, it is important to understand the age/size structure of walleye incidental catch and discarding rate from these fisheries in order to better understand the survival rate and population dynamics of the species.

Fisheries managers often focus on targeted species and make management decisions to reduce fishing pressure. However, questions may be raised about the effectiveness of the management action by only changing the targeted fishery for a species. This study provides a reference for Lake Erie walleye commercial fisheries. Lake Erie fisheries managers need to take into account incidental catch of walleye from other fisheries when considering walleye management options for the lake. An average of about 530,000 kg of walleye each year can be expected in form of incidental catch from Ontario commercial fisheries at the current conditions. However, the level will depend on walleye incidental catch fisheries and other factors.

Walleye in Lake Erie is a seasonally-migratory species. During late spring or early summer, some walleye in the west basin start an eastward migration to the central and east basins. Likely during late fall or early winter, those migrants in the central and east basins return to the west basin and prepare for reproduction in the coming spring (Henderson and Wong, 1994; Wang et al, 2007). Walleye migration patterns along the long axis of the lake (northeast to southwest) likely create directional patterns of maximum continuity of the species density detected

in this study. During late fall and early winter, walleye likely cease migrations and severe winter environmental conditions could create patches or fragments of walleye habitat that cause strong schooling behaviour of the species. The spatial pattern with multiple peaks of walleye density observed in this study could be resulted from such schooling behaviour.

It is not surprising that the current assessment protocol underestimated the incidental catch effort compared to the geo-statistical approach used in this study. The protocol uses the arithmetic mean of the walleye-targeting CPUEs to derive incidental catch effort. An arithmetic mean can be one of the best measurements of center tendency of data with a normal or approximately-normal distribution. However, the walleye-targeting CPUE is typically positively skewed and the arithmetic mean is pulled in the direction of a few large measurements and thus, overestimated the central tendency compared to other measurements such as median and mode. Because the overestimated CPUE is the denominator of the calculation of the incidental catch effort, the estimated effort is thus underestimated. In addition, the protocol ignores the spatial distribution of the CPUE. Underestimating fishing effort consequently results in overestimating walleye abundance and underestimating fishing mortality. This study detected significant spatial patterns of walleye density due to walleye migration and schooling behaviours and, more importantly, incorporated the detected spatial patterns to the estimation of the incidental catch effort. The accuracy of incidental catch effort is expected to be improved over the current assessment protocol, and the geo-statistical approach applied in this study is suggested for Lake Erie walleye commercial fishery and could also be modified and applied to other fisheries with similar incidental catch concerns for both marine and freshwater fisheries.

Both the geo-spatial approach developed in this study and the current assessment protocol use the targeted CPUE to standardize the incidental catch effort. This demonstrates the importance of correctly recording the walleye-targeted catch and effort. Several procedures are involved in fishers' catch calculation and estimation, such as voluntarily reporting in the DCR, port officers' monitoring at docks and staff's weighing at processing plants. However, the effort is only reported in the DCR and potentially carries large uncertainties. Currently, there is a proposal that Lake Erie commercial gillnet fishermen use GPS transponders when they are deploying gillnets. The transponder has its own identification number for each fishing boat and can instantaneously transfer net-setting status including time, location, net length, direction and duration. The proposed technique is still in the stage of field experiments and potentially increases the accuracy of gillnet effort measurement.

Acknowledgements

The Ontario commercial fishing licence holders of Lake Erie recorded the DCRs. The staff of the LEMU of OMNR helped to process the DCRs and to produce the Ontario commercial fisheries database, especially Bob Sutherland helped with organizing the database, Debbie Boland and Aida Baptista helped with data entry. Li Wang from Dr. Ciborowski's lab in the University of Windsor helped with the GIS modelling and mapping. Comments and suggestions from Megan Belore, Andy Cook, Llord Mohr, Rich Drouin, Nigel Lester, and Sandra Orsatti significantly improved the manuscript. The project was financially supported by the Ontario's Fish and Wildlife Special Purpose Account (SPA) and Ontario Funding for Canada-Ontario Agreement (7-02) (COA) Respecting to the Great Lakes Basin Ecosystem to Y.Z.

References

- Beverton, R. J. H and S. J. Holt. 1957. On the dynamics of exploited fish populations. Chapman and Hall, London, Facsimile reprint, 1993.
- FAO (Food and Agriculture Organization of the United Nations), 1996. Report of the technical consultation on reduction of wastage in fisheries. Tokyp, Japan, 28 October- 1 November 1996. FAO fisheries Report, No.547. Rome, FAO, 1996. 27p.
- Gulland, J. A. 1970. The fish resources of the oceans. FAO fisheries Technical Paper No. 97. 4p.

- Hatch, R. W., S. J. Nepszy, K. M. Muth, and C. T. Baker. 1987. Dynamic of the recovery of the western Lake Erie walleye (*Stizostedion vitreum vitreum*) stock. *Canadian Journal of Fisheries and Aquatic Sciences* 44 (suppl. 2): 15-22.
- Henderson, B.A., R. Hass, R. Knight, R. Lorantas, and R. Rawson. 1990. Quota estimation for Lake Erie walleye: model and result. Statistics and Modelling Group Report, Ontario Ministry of Natural Resources, Ontario, Canada. 48p.
- Henderson, B. A. and Wong, J. L. 1994. Migration of walleye in Lake Erie: life history tactics for optimum growth and reproduction. Report to Walleye Task Group of Lake Erie Standing Technical Committee. The Ontario Ministry of Natural Resources, Aquatic Research and Development Section, Maple, Ontario, Canada. 85 pp.
- Isaaks, E. H. and Srivastava, R. M. 1989. An introduction to applied geostatistics. Oxford University Press, Inc. New York. 561p.
- Legendre, P. and L. Legendre. 1998. Numerical ecology. 2nd English edition. Elsevier Science B.V., Amsterdam, the Netherlands. 853p.
- Locke, B., M. Belore, Cook, A., Einhouse, D., Kayle, K., Kenyon, R., Knight, R., Newman, K., Ryan, P., and Wright, E. 2005. Lake Erie Walleye Management Plan. Lake Erie Committee, Great Lakes Fishery Commission. 45p. [online] Available from http://www.glfc.org/lakecom/lec/WTG_docs/other_reports_and_docs/wmp20051207.pdf
- Pâroma, J., and R. Roa. 2003. Acoustic-geostatistical assessment and habitat-abundance relations of small pelagic fish from the Colombian Caribbean. *Fisheries Research* 60: 309-319.
- Regier, H.A., V.C. Applegate, and R.A. Ryder. 1969. The ecology and management of the walleye in Western Lake Erie. Great Lakes Fisheries Commission Technical Report No. 15, 101p.
- Scott, W.B. and E.J. Crossman. 1998. Freshwater fishes of Canada. Galt House Publications Ltd, Oakville, Ontario. 966p.
- Walleye Task Group (WTG). 2009. Report of the Lake Erie Walleye Task Group to the Standing Technical Committee, Lake Erie Committee of the Great Lakes Fishery Commission. 33 pp. [online] Available from http://www.glfc.org/lakecom/lec/WTG_docs/annual_reports/WTG_report2008.pdf
- Wang, H., E. S. Rutherford, H. A. Cook, D. W. Einhouse, R. C. Haas, T. B. Johnson, R. Kenyon, B. Locke and M. W. Turner. 2007. Movement of Walleyes in Lake Erie and Lake St. Clair Inferred from Tag Return and Fisheries Data. *Transactions of the American Fisheries Society* 136:539-551.
- Zhao, Y., Shuter, B. J., and Jackson, D. A. 2008. Life history variation parallels phylogeographical patterns in North American Walleye (*Sander vitreus*) populations. *Canadian Journal of Fisheries and Aquatic Sciences* 65: 198-211.
- Zhao, Y., Einhouse, D.E., & MacDougall, T.M. 2011. Resolving some of complexity of a mixed origin walleye (*Sander vitreus*) population in east basin of Lake Erie using a mark-recapture analysis. *North American Journal of Fisheries Management*. Vol. 31 (2): 379-389.

Figure 1. Lake Erie and fisheries management units (MUs) and grids for Ontario commercial fisheries.

Note: MU1-3 represent walleye quota allocation area for Ontario.

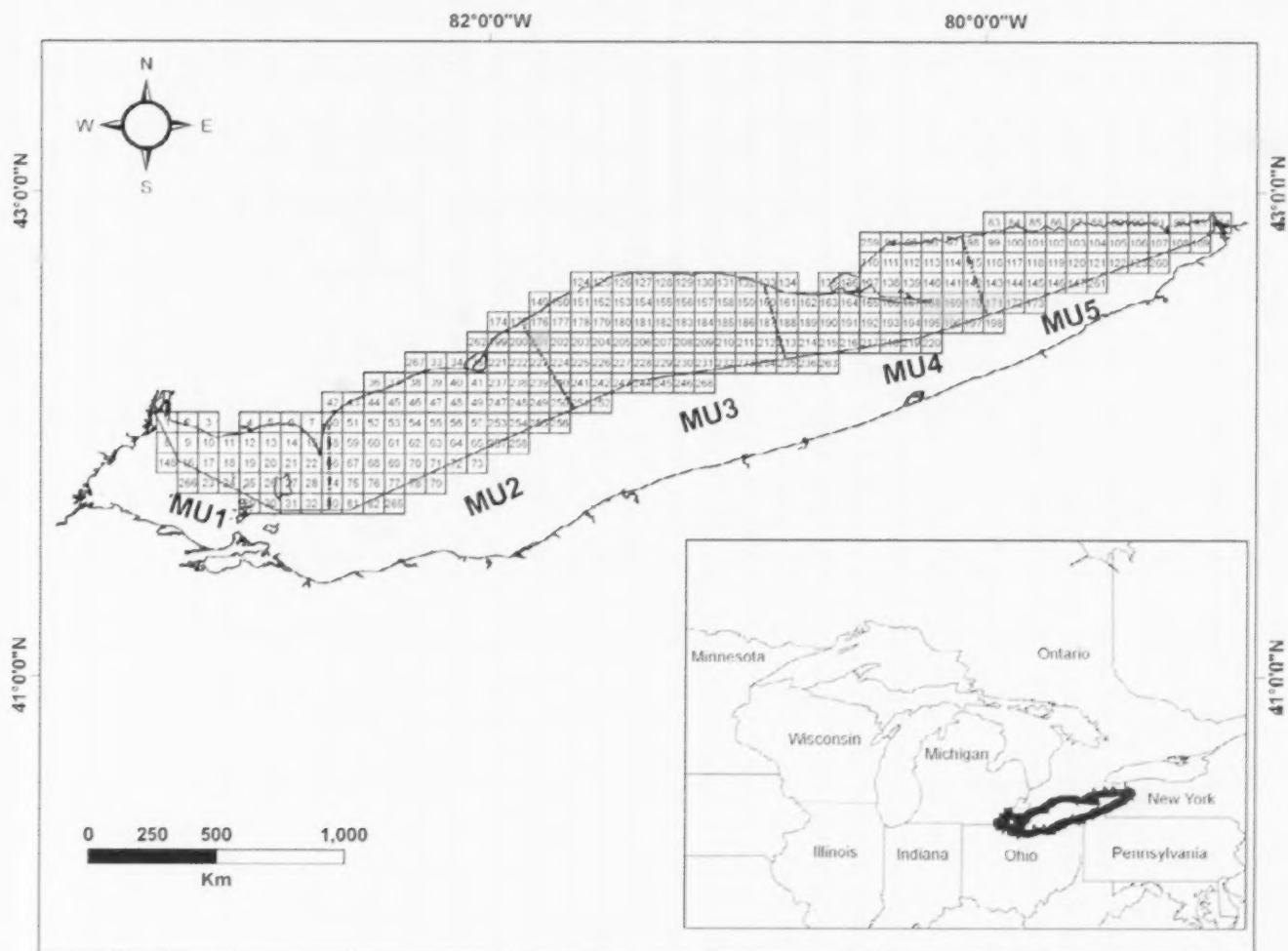


Figure 2. Time series (1993 to 2009) plot of (a) annual total harvest of walleye from Ontario Lake Erie commercial fisheries by management unit (MU); (b) annual mean of the Catch-Per-Unit-Effort (CPUE) of walleye-targeting gillnet by management unit (MU); (c) annual percentage of incidental catches in the total harvest.

Note: the CPMS was implemented from 2001-2003, see the text for the details.

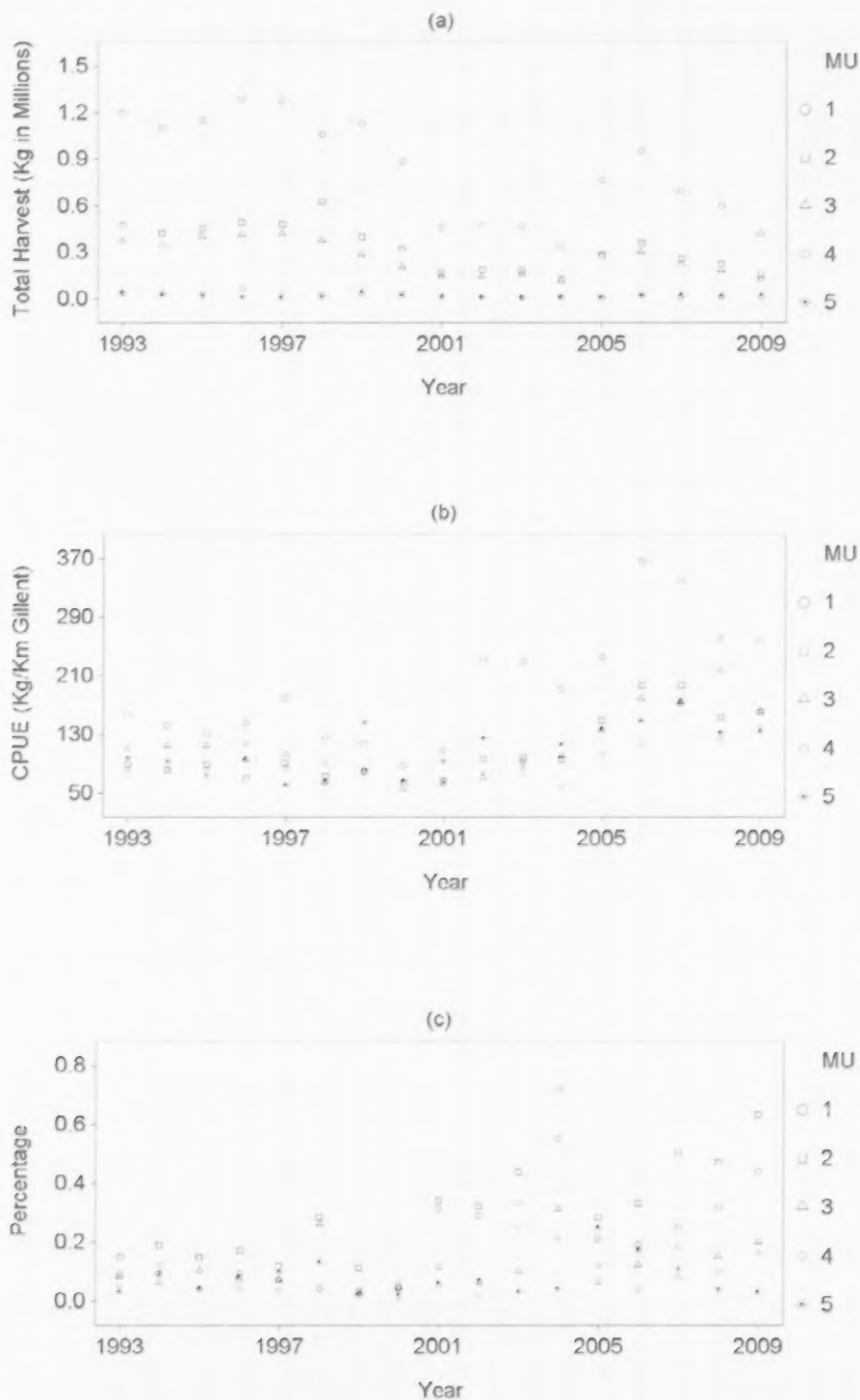


Figure 3. For Lake Erie walleye from 1993 to 2009, (a) The calculated Ontario walleye incidental exploitation rate (u) and fishing mortality rate; (b) A scatter plot of annual total incidental catches from Ontario commercial fisheries versus annual lakewide abundance of age 2 and older fish; (c) a linear relationship between the lakewide TAC and the proportion of incidental harvest in the total commercial harvest.

Note: CPMS was implemented from 2001 to 2003, see the text for more details.

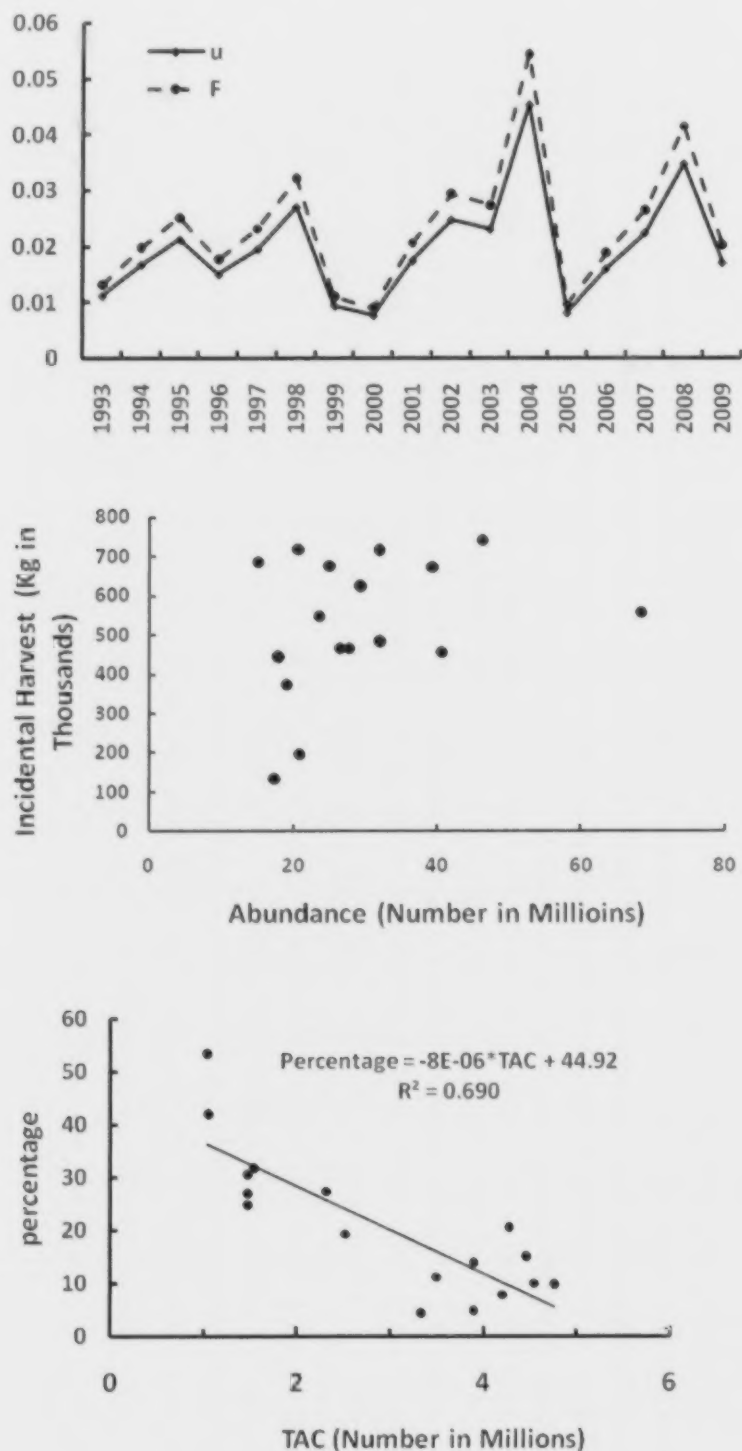


Figure 4. Time series of walleye incidental catch composition by weight from Ontario commercial fisheries in Lake Erie (a) by fishing gear type; (b) by target species.

Note: (a) GN-gillnet; TW-trawl; PD_TP-impound or trapnet; (b) WB-white bass; YP-yellow perch; LW-lake whitefish; WP-white perch; RS-rainbow smelt.

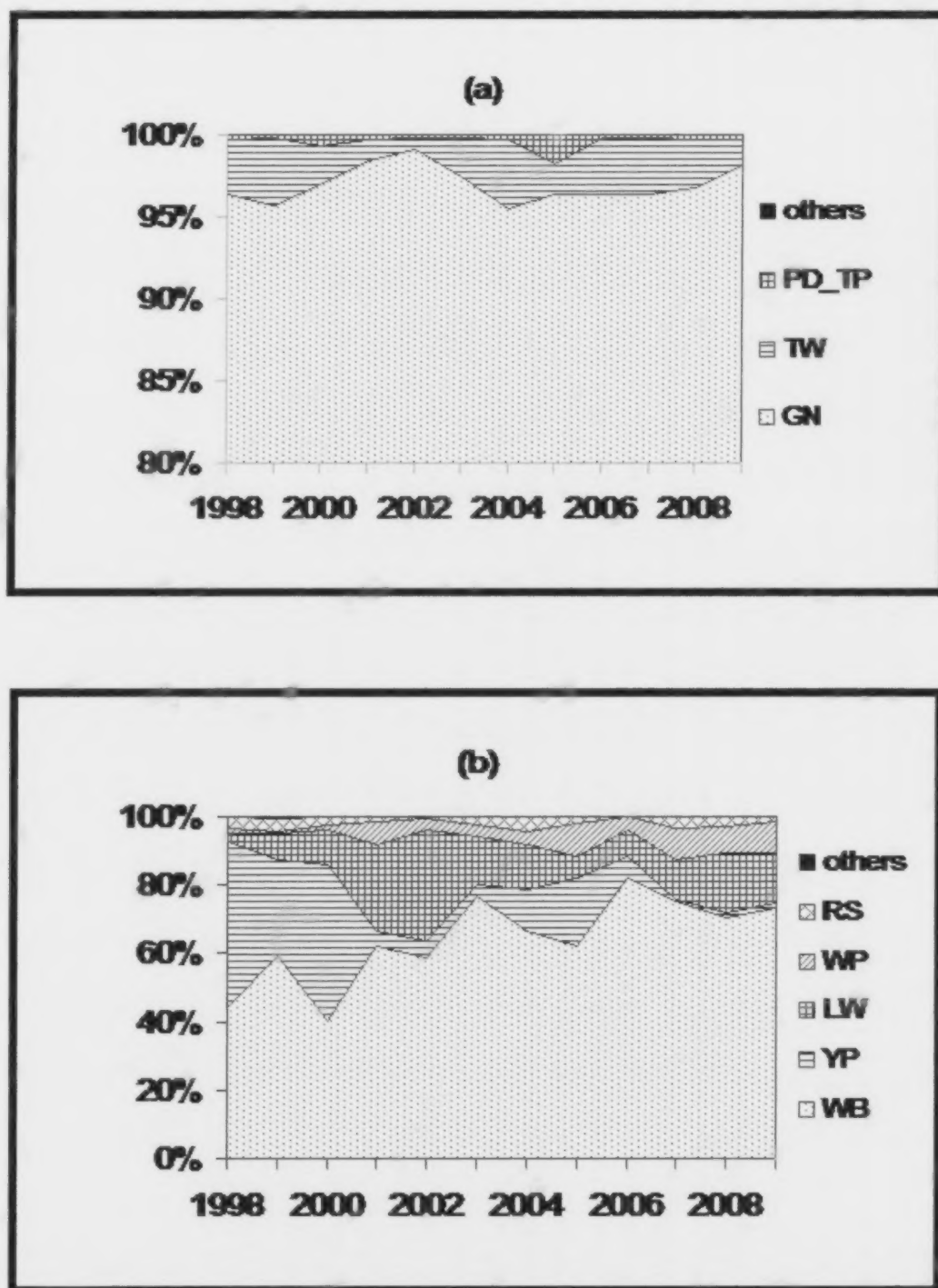


Figure 5. Interpolated maps of Ontario walleye quota area (MU1-3) for the walleye-targeting CPUE (kg/km) of Ontario gillnet commercial fishery in Lake Erie from April to December in 2004.

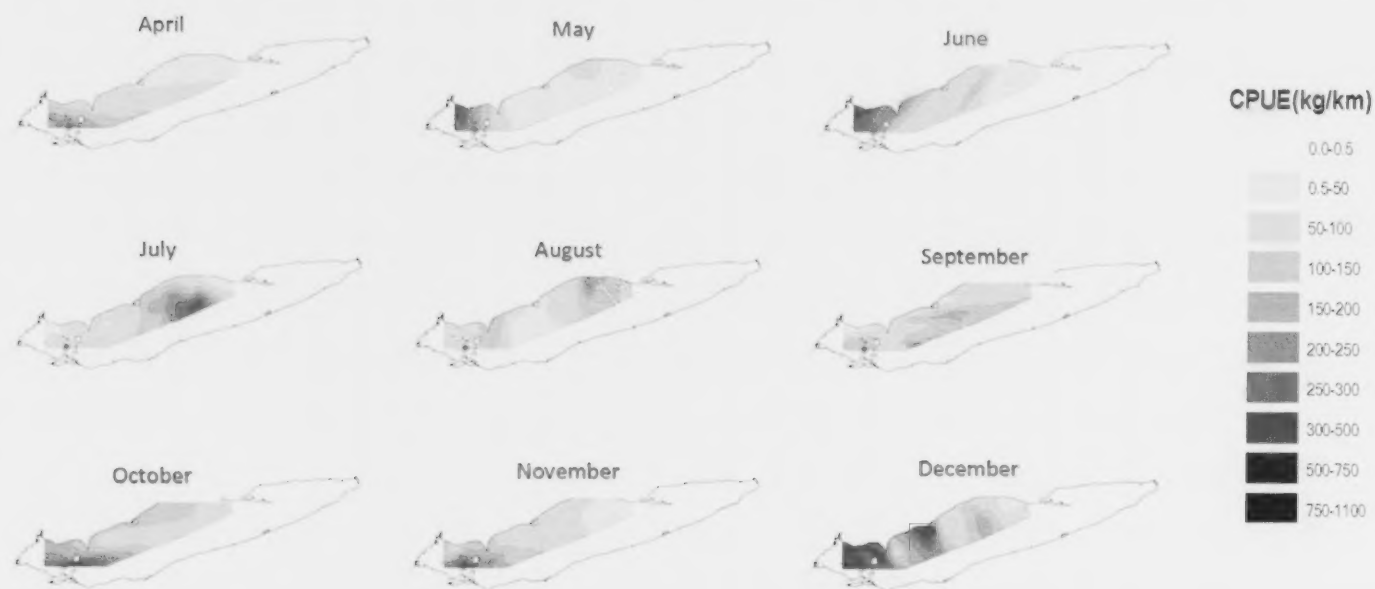


Figure 6. Interpolated maps of Ontario walleye quota area (MU1-3) for the walleye-targeting CPUE (Kg/Km) of Ontario commercial fishery in Lake Erie from April to December in 2005.

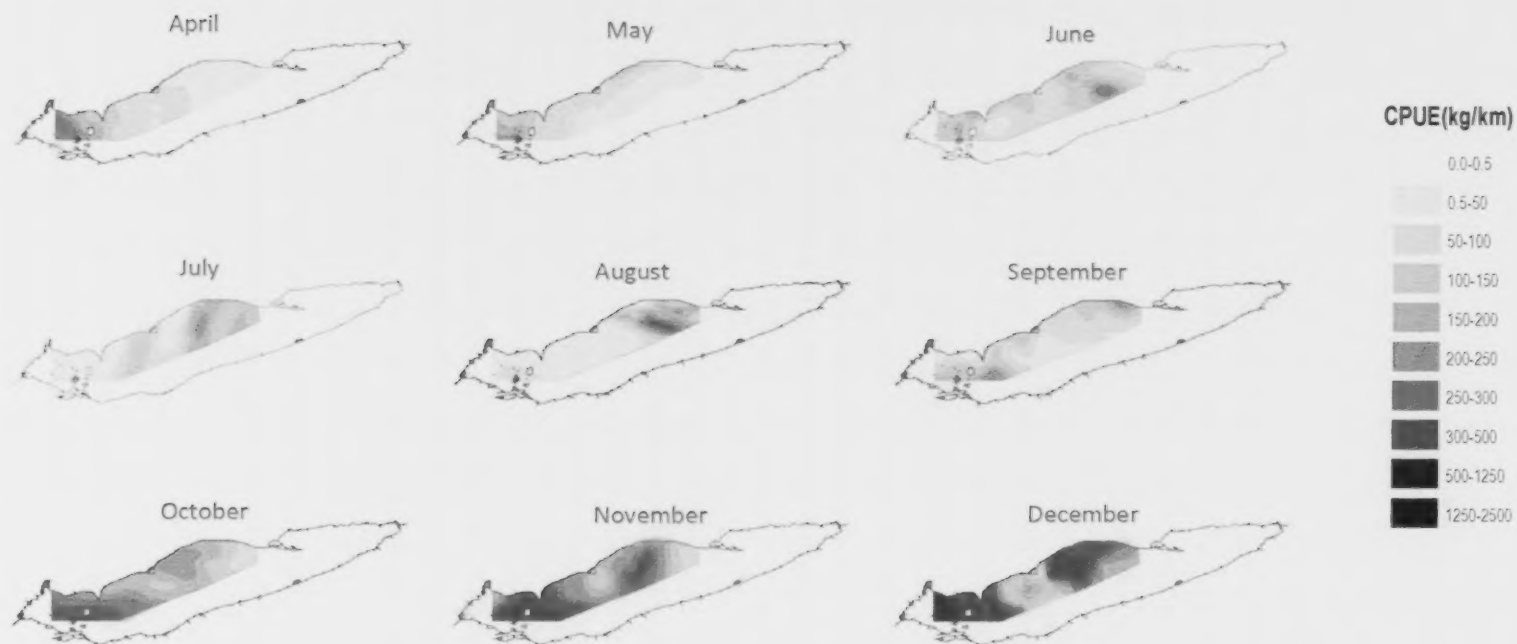


Figure 7. Comparison of the estimated incidental catch fishing efforts the total effort, i.e. sum of targeted effort (Target) and incidental effort for Ontario Lake Erie commercial fishery between the geo-statistical approach (G.Statistical) and the current assessment protocol (C. Protocol) in (a) 2004 and (b) 2005.

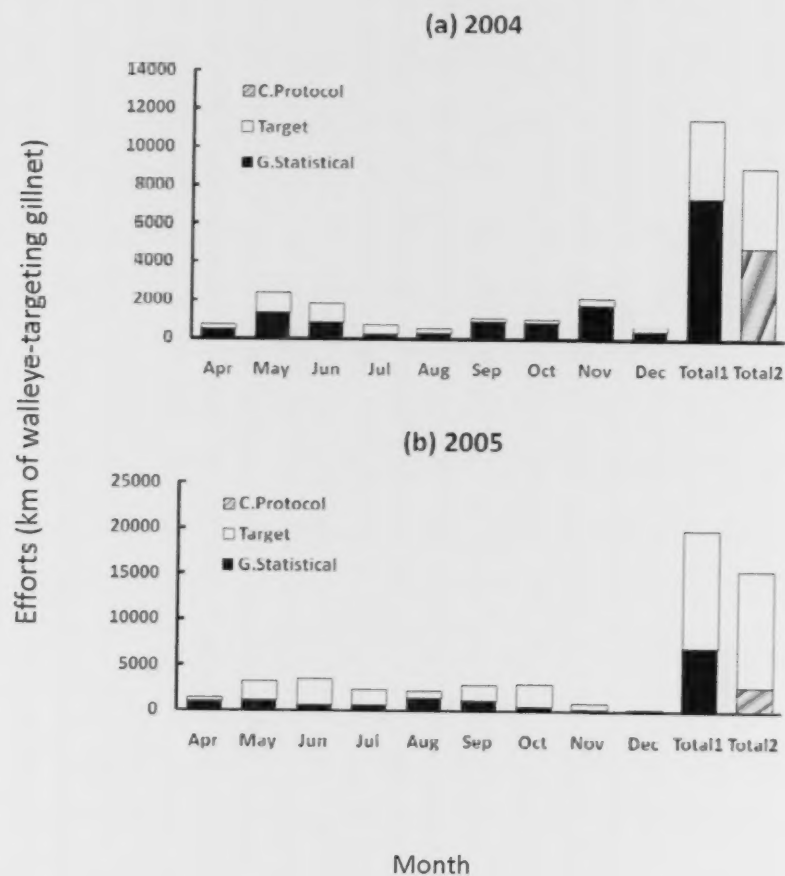


Table 1. The configurations and estimated semi-variogram parameters for interpolating the walleye-targeting catch-per-unit-effort (CPUE) for Lake Erie Commercial Fishery from April to December in 2004 and 2005 using ordinary kriging.

Table 1: The configurations and estimated semi-variogram parameters for interpolating the walleye-targeting catch-per-unit-effort (CPUE) for Lake Erie Commercial Fishery from April to December in 2004 and 2005 using ordinary kriging

Month	April		May		June		July		August		September		October		November		December	
Year	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Transform ¹	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log	Log
Trend ²	1	1	1	2	1	2	1	2	1	1	1	2	1	1	1	2	1	2
Anisotropy ³	NW-SE	NE-SW	NW-SE	NE-SW	NE-SW	NE-SW	ISO	NE-SW	N-S	NE-SW	NE-SW	NW-SE	NE-SE	E-W	NE-SW	ISO	NW-SE	NW-SE
Nugget	0.328	0.479	0.863	0.39	0.35	0.214	0.405	0.173	0.326	0.146	0.608	0.348	0.015	0.296	0.306	0.253	0.25	0.306
Sill	0.337	0.51	1.1	0.415	0.59	0.501	1.249	0.563	0.704	1.397	0.864	1.194	0.033	0.501	0.674	0.655	0.999	0.74
Neighbour ⁴	5	5	15	15	5	15	21	15	10	21	5	5	10	15	15	35	15	5
Sector ⁵	8	4	8	1	4	4	8	8	8	8	8	8	8	8	4	8	1	1

1. transformation of the CPUE to meet normality assumption: log—logarithm transformation

2. trends detected and removed prior to variogram modelling: 1-the first order trend, 2-the second order trend

3. direction influences indicating the direction with maximum spatial continuity: NE=northeast, NW=northwest, SE=southeast, SW=southwest, ISO=isotropy

4. number of neighbours used for kriging (derived from the cross-validation study described in the text)

5. number of sectors used for kriging (derived from the cross-validation study described in the text)

MNR 52722

ISBN 978-1-4606-1851-6 (Print)

ISBN 978-1-4606-1852-3 (PDF)